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Comparing H and V MI BPMs Using the Upgraded System

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Abstract

This note presents a first look at data from a vertical MI BPM, taken using the upgraded MI BPM system. This data is compared with data from a horizontal MI BPM taken with the same upgraded system. Using these data the RMS spread of the closed orbit position data, for stable beam conditions, is 14.8 μm for the horizontal BPM and 9.7 μm for the vertical BPM. If one ignores possible contributions from true beam motion, these correspond to the 1 σ position resolutions. This note also shows closed orbit data from the horizontal BPM from two additional MI states, mixed mode and beam to the switchyard. Data from this last mode is used to plot resolution as a function of intensity.

Contents

1 Introduction

The first data presented in this note are from the horizontal MI BPM 412 and the vertical MI BPM 413. Both flash data and closed orbit data will be presented. Both types of data were taken using MI State 28, slip stacking only, which has a master reset of TCLK $29. In this state two batches are injected, with slip stacking, and then extracted to the antiproton production target.

Most of the data was taken at about 10:15 AM on December 22, 2005. The exception is the horizontal closed orbit data for the H BPM; that was taken on December 12, 2005 at about 4:15 PM. The reason for using old data is simply that I messed up taking the closed orbit data for the H BPM on the morning of the 22nd; fortunately I had some older data of the same state. I believe that the Echotek programming was the same for the two days. The horizontal and vertical flash data were taken about an hour apart.

The flash data were acquired by logging in to the front end and writing the data for state 28 to disk. Before writing the data, I temporarily disabled flash data taking to ensure that all data were for the same instance of the MI cycle.

The closed orbit data were acquired by watching a fast time plot of I:BEAM, triggered on $29, and writing the abort buffer to disk following an instance of state 28. The abort buffer holds about 8 seconds of data, taken at a rate of 500 Hz.

2 Flash Data for State 28

Figure 1 shows the sum signal, the position signal and the Fourier Transforms from both the H and V BPMs. The data shown is for the first of the two injections. Figure 2 shows details of the Fourier transforms from the previous figure. The details show the low frequency region and the region near the betatron line.

The synchrotron frequency for the MI at injection energy is around 200 Hz. There is a small amplitude at that frequency in the position data for the horizontal BPM; the synchrotron line can be seen strongly in the Beams-doc-2060, figures 18 (upper two plots) and 20 (lower two plots). Presumably the injection shown in this figure was better tuned and the synchrotron line has a small amplitude.

Dave Capista tells me that, when slipping is on, the MI has two sets of cavities energized at frequencies separated by about 1200 Hz; a beat will be present at this frequency. The dominant line in the position data for the horizontal BPM has a line at about 1.4 kHz. This frequency is the sum of the beat frequency plus the synchrotron frequency. The line is absent in the data from the vertical BPM since both of the phenomena that contribute to this line, the beat frequency and the synchrotron motion, are felt only in the horizontal plane.

In Beams-doc-2060 it was demonstrated that the rate at which bunches slip out of the Echotek gate is also 1.4 kHz.

The line at 1.4 kHz does appear in the sum signal for both the horizontal and vertical BPMs. I don't yet know the explanation for this.

The Fourier transform of the sum signal has a second strong line at about 600 Hz; it is present in both the horizontal and vertical data. The line is also present in Beams-doc-2060, figures 17 (upper two plots) and 19 (lower two plots). This line is not caused by bunch length oscillations; if it were it would be at twice the synchrotron frequency, about 400 Hz and its frequency is clearly different from that. For now this line remains unexplained.

The lower right plot in Figure 2 shows the betatron tunes in the two planes. By eye I estimate that the tune split is about 1.5 ± 0.5 bins, or about 140 ± 45 Hz.

Figure 3 shows a summary of the data for flashes 2 and 3. Flash 2 measures the injection of the second bunch, while flash 3 measures the extraction. At the time these measurements were made, the house delays for injection from the booster were set relative to the AA marker. This means that, if the first injection is properly timed in, subsequent injections will not be. See beams-doc-2060 for details. More recent data has this problem fixed.

3 Closed Orbit Data for State 28

Figure 4 shows the closed orbit data for a full cycle of state 28, for both horizontal and vertical BPMs. As expected, when the first batch starts to slip, the beam moves only in H, not in V.

Figure 5 shows a detail of these plots focusing on the time when only batch 1 is in the MI. The position data suggests that the slipping starts 7 or 8 ticks of the 500 Hz clock after the injection; this corresponds to 14 or 16 ms, which is longer than the expected value of about 8 ms. Does this mean that the slipping takes 6 or 8 ms to accelerate enough that it can be seen?

Figure 6 shows a second detail of the plots in Figure 4, the time just before and after extraction. Actually it shows the detail from a different cycle of the same state. It was previously noted that the sum signal for the H BPM has a small step just before the main extraction; this was explained as a artifact of a bunch rotation. This is also present in the data for the vertical BPM.

In an email from January 3, Alberto pointed out that the period of stable beam position after the ramp and just before extraction starts 1.21 s after the TCLK that starts the state. The vertical red lines in Figure 6 mark an interval after 1.21 s during which both the sum and position signals are clearly stable. For both the horizontal and vertical BPMs the RMS spread of the position about its mean value was computed. In this computation, only the data between the vertical red lines was used. This RMS width contains contributions from both the resolution of the BPM system and from true beam motion; so it is an upper limit for the 1 σ resolution of the BPM system. If we attribute the full RMS to measurement resolution, the results are a 1 σ resolution of 9.7 μm for the vertical BPM and 14.8 μm for the horizontal BPM. Both of these statisfy the required resolution, given in Table 7 of Beams-doc-1786-v7, of $<$50 μm for 3 σ resolution. Note that these numbers are measured with just two batches in the machine, which is less than the maximum intensity.

In the left hand plots of Figure 5, one sees that the sum signal becomes continuously smaller as the beam begins to slip. I will offer a possible explanation. When the beam moves to a smaller radius, its rotation frequency also changes. Since this frequency is away from the center frequency of the Echotek digital filter, the digital filter attenuates the signal a little. As the beam moves to an even smaller radius, the rotation frequency moves farther from the center frequency of the Echotek digital filter; and the signal is attenuated even more.

In Beams-doc-2060 it was reported that, when slipping is underway at its full speed, the rate at which the bunches slip out of the Echotek gate is 1.4 kHz. Figure 1 in Beams-doc-2101-v2 shows that at 1.4 kHz away from the center frequency of the digital filter, the filter attenuates a little more than 6 db. This corresponds to a little more than a 50% loss of sum signal. An effect of about this size is observed in the sum signal for both the horizontal and vertical BPMs.

4 Closed Orbit Data for MI States 5 and 24

Figure 7 shows some additional closed orbit data for the H BPM only. It was taken about about 6:30 PM on December 22, 2005. The gain settings for this data were the same as for the closed orbit data shown earlier.

The upper two plots show the sum and position information for MI state 5, slip-stacking for anti-proton production plus beam to NUMI. The lower two plots show the same information for MI state 24, which sends beam in a slow spill to MTEST/MIPP.

Compare the sum signal for these two data sets, a peak of about 120 for state 24 and a peak of about 11,000 for state 5. This can also be compared to the peak sum signal for the horizontal data in Figure 4, about 3000. All of these data were taken with the same gain settings on the transition board. In the data for state 5, the bottom left plot in Figure 7, the noise level can be seen; it is about 3 to 4 EU. The noise level is the same in the data for states 5 and 28.

In the bottom right hand plot of Figure 7, one can see that the position resolution degrades as the beam intensity drops. To quantify this, the data between the two red dashed vertical lines were used. In the top plot of Figure 8, the RMS spread of the position data is plotted as a function of the mean sum signal. The rightmost point includes the data between ticks 1500 and 1549; the quantities represented by the plotted point are the RMS position and the mean sum, both running over these 50 measurements. The error on the RMS is RMS/$\sqrt{2n}$, where $n = 50$ is the number of measurements. The error on the sum is too small to worry about. The second point from the right uses the data between ticks 1600 and 1649; and so on. The middle plot in the figure repeats these data but adds one more point, the sum and RMS position spread from MI state 28, reported above.

I was not able to find an interval in the state 5 data during which the position was stable enough to measure an RMS spread.

The bottom plot of Figure 8 shows, for the same data set as the top plot, the mean position as a function of the mean sum signal. The rightmost point uses the same 50 measurements as the rightmost point in the top plot; and so on. For the bottom plot, however, the mean of the 50 position measurements is plotted against the mean of the 50 sum measurements. There is some evidence for a slow draft to smaller values of the position as the intensity decreases. But this is not a large effect. Indeed the confidence level that all 35 points are consistent with being flat is 1%; when the two points at either end are excluded, the confidence level that the remaining data are flat is 29%. I conclude that from this that 50 points per sample was a sensible choice for measuring the RMS.

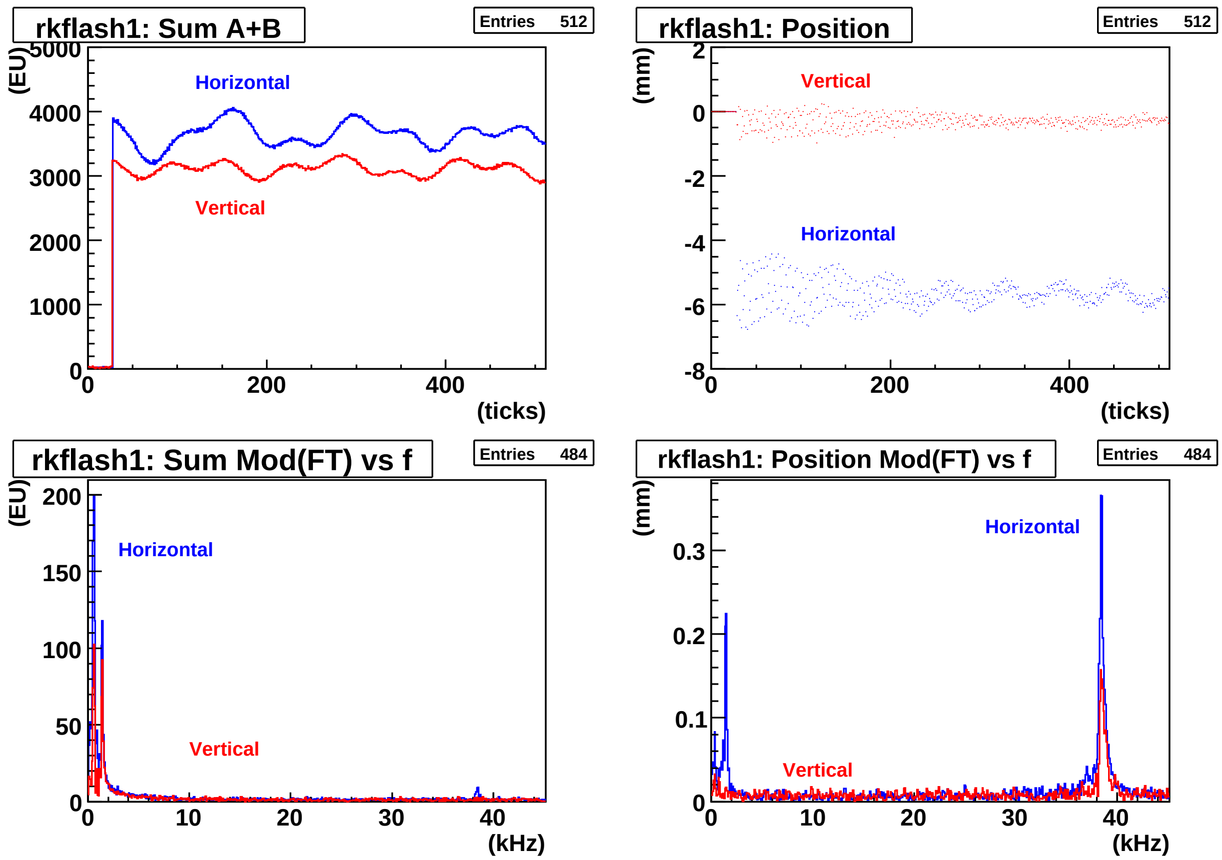

Figure 1: Flash turn by turn data from both BPMs for the first injection. The upper left plot show the sum signal; the upper right plot shows the position; the lower left plot shows the magnitude of the Fourier transform of the sum signal; the lower right plot shows the magnitude of the Fourier transform of the position. Details of the transforms are shown in the next figure.

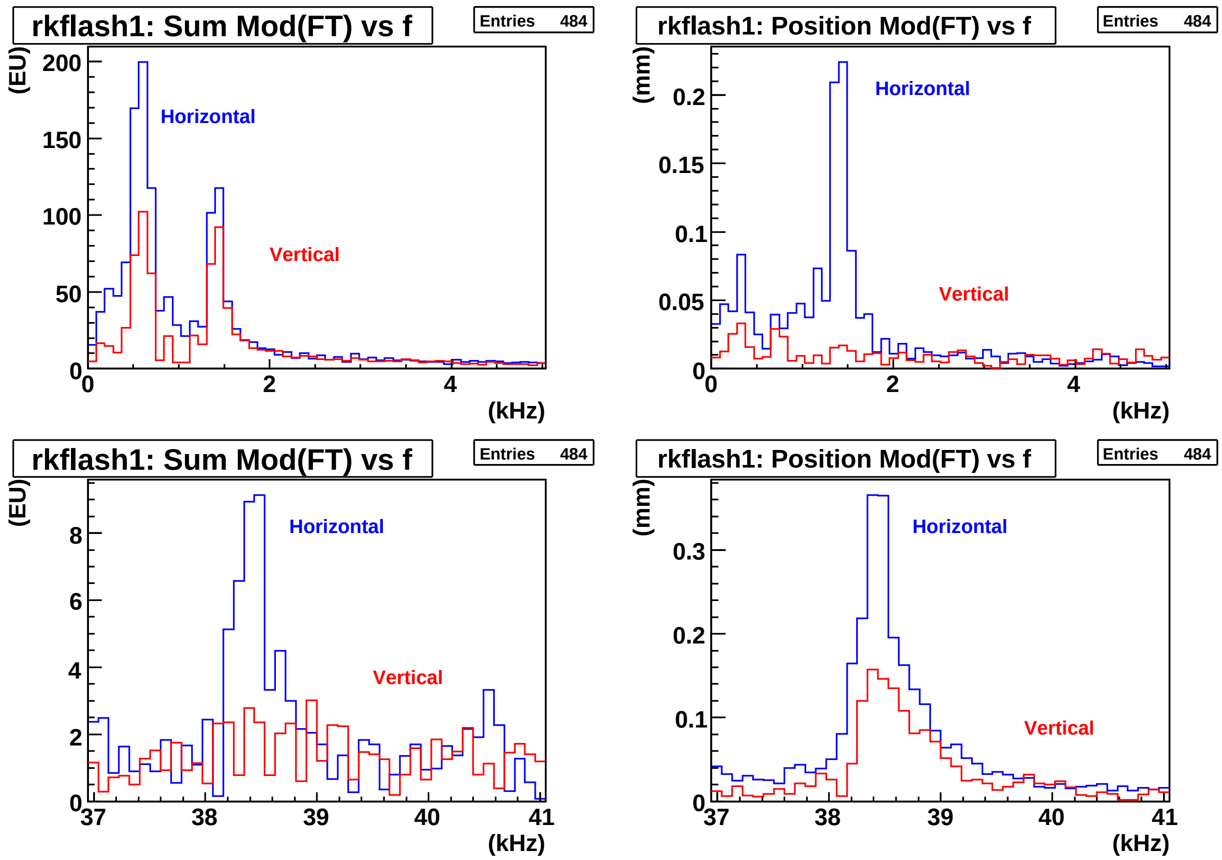

Figure 2: Details of the lower plots in Figure 1. The left plots show details of the Fourier transform of the sum signal while the right plots show the same detail for the position. Synchrotron motion is absent in the position data form the Vertical BPM. Each bin is about 92 Hz wide and on this scale it is hard to resolve the horizontal/vertical betatron tune split.

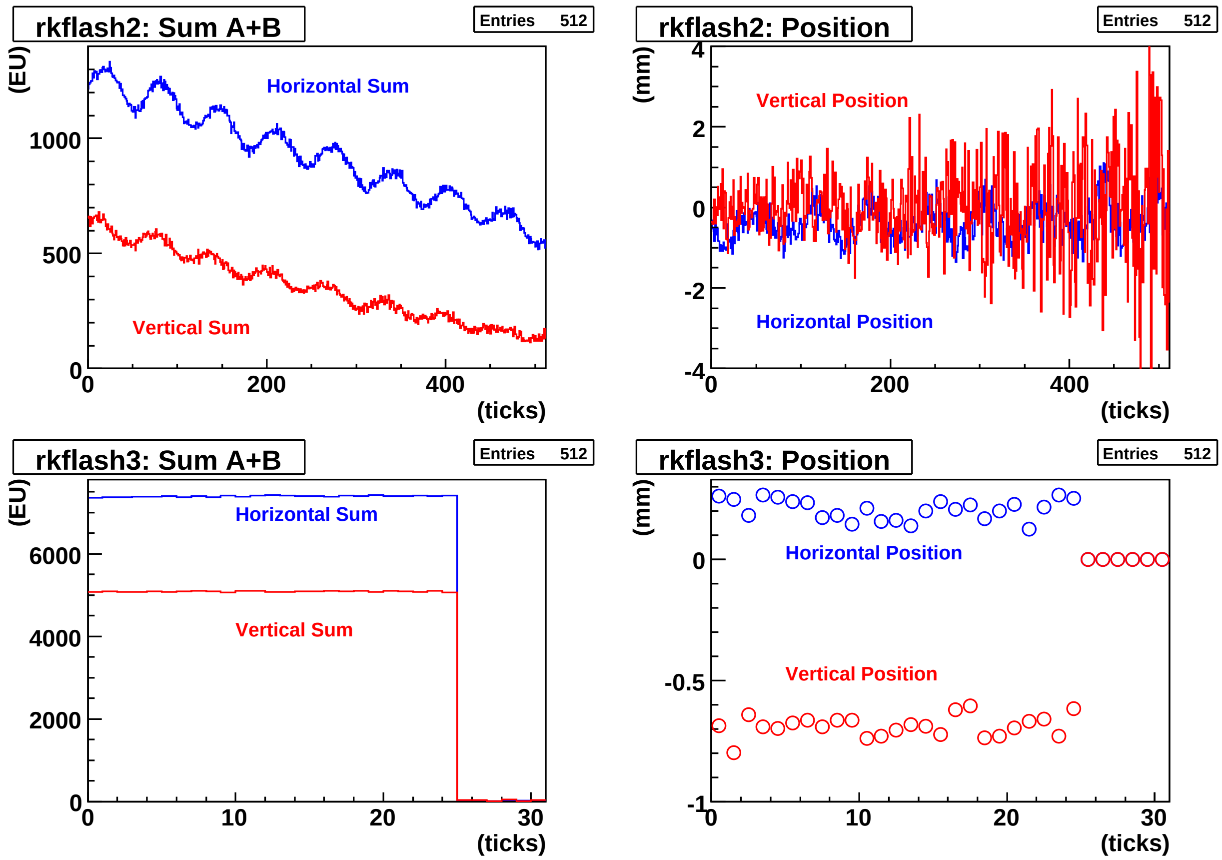

Figure 3: Sum and position information for flashes 2 and 3; flash 2 is the second injection and flash 3 is the extraction. The upper two plots are for flash 2 and the lower for flash 3. In this data the position is reported as 0 when the sum signal is below threshold.

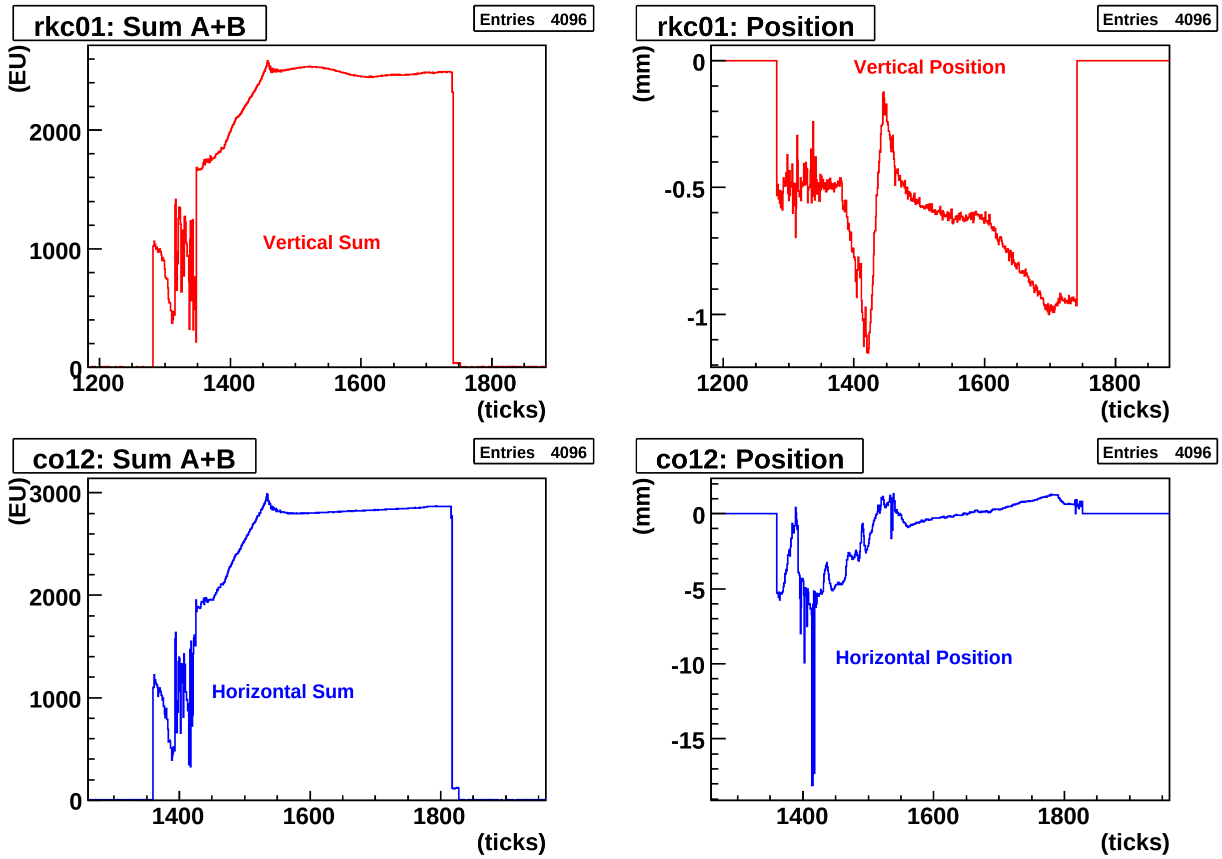

Figure 4: Closed orbit data for the slip stacking state. The left plots show the sum signal while the right plots show the position. The upper plots show the vertical BPM while the lower plots show the horizontal BPM. Note that the vertical position is stable when the first batch is moved to the orbit with a smaller radius. Note the large scale difference for the position data for the two BPMs.

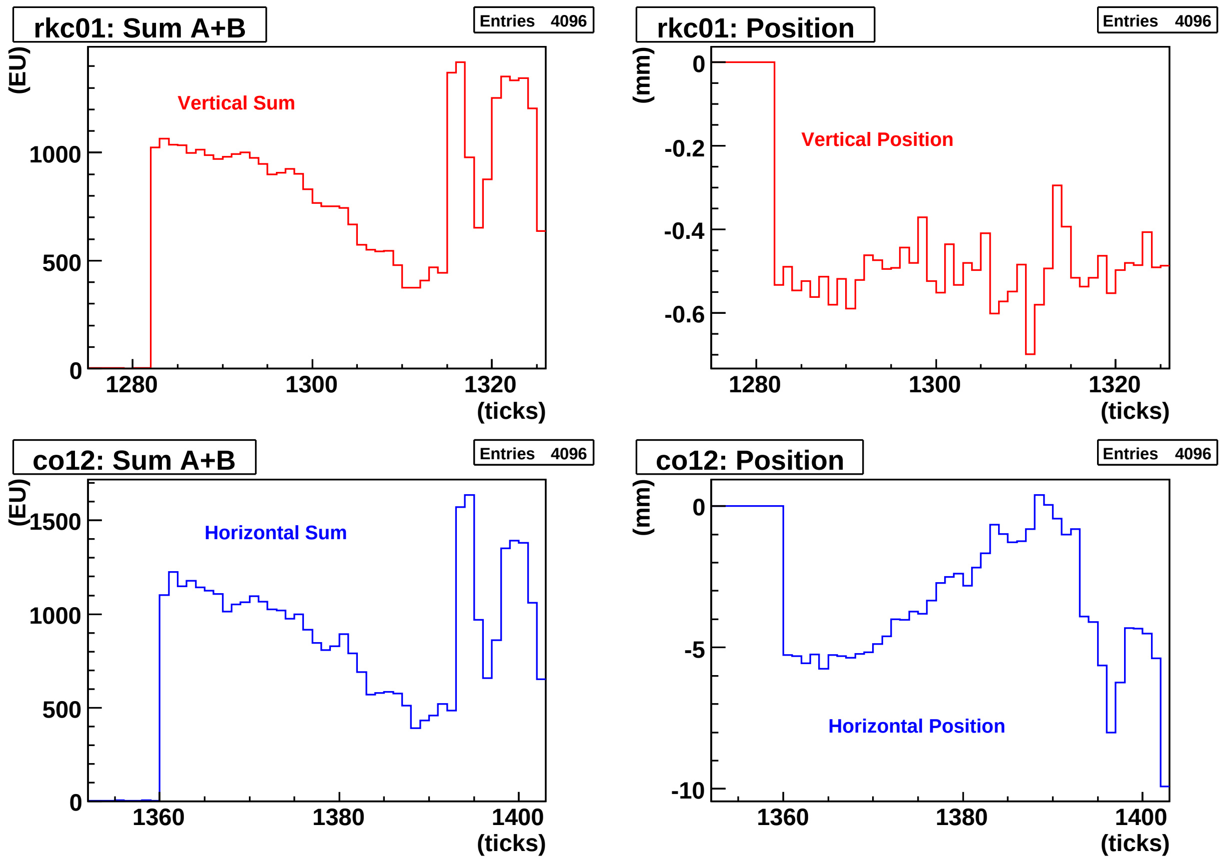

Figure 5: Detail of Figure 4, zoomed in to show the time between injection of the two batches.

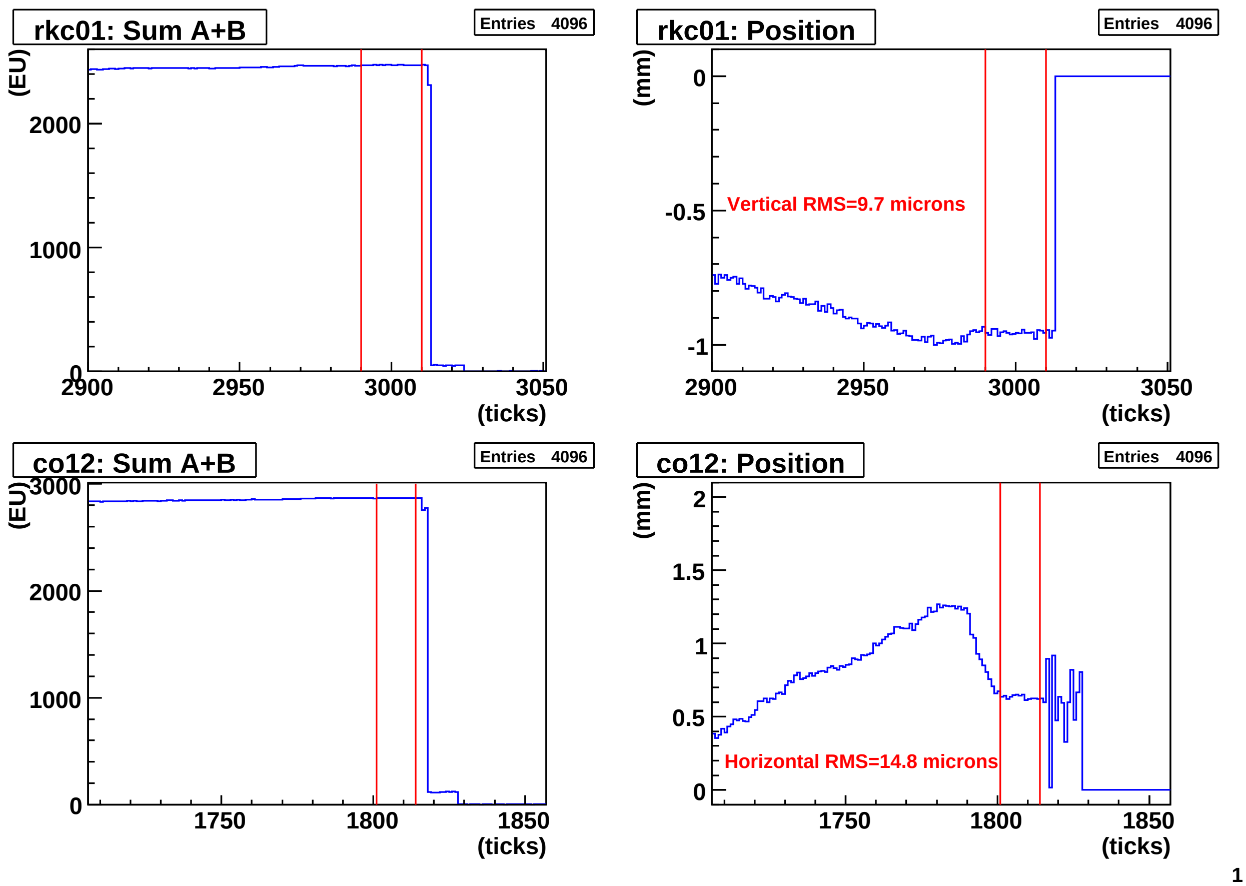

Figure 6: Detail of Figure 4, zoomed in to show the time just before and after extraction. (Actually it is a from a different cycle of the same state; but the information content is the same.) The red vertical lines mark the regions used to measure the position resolution. The RMS about the mean of the position data between these lines in overlayed on each right hand plot.

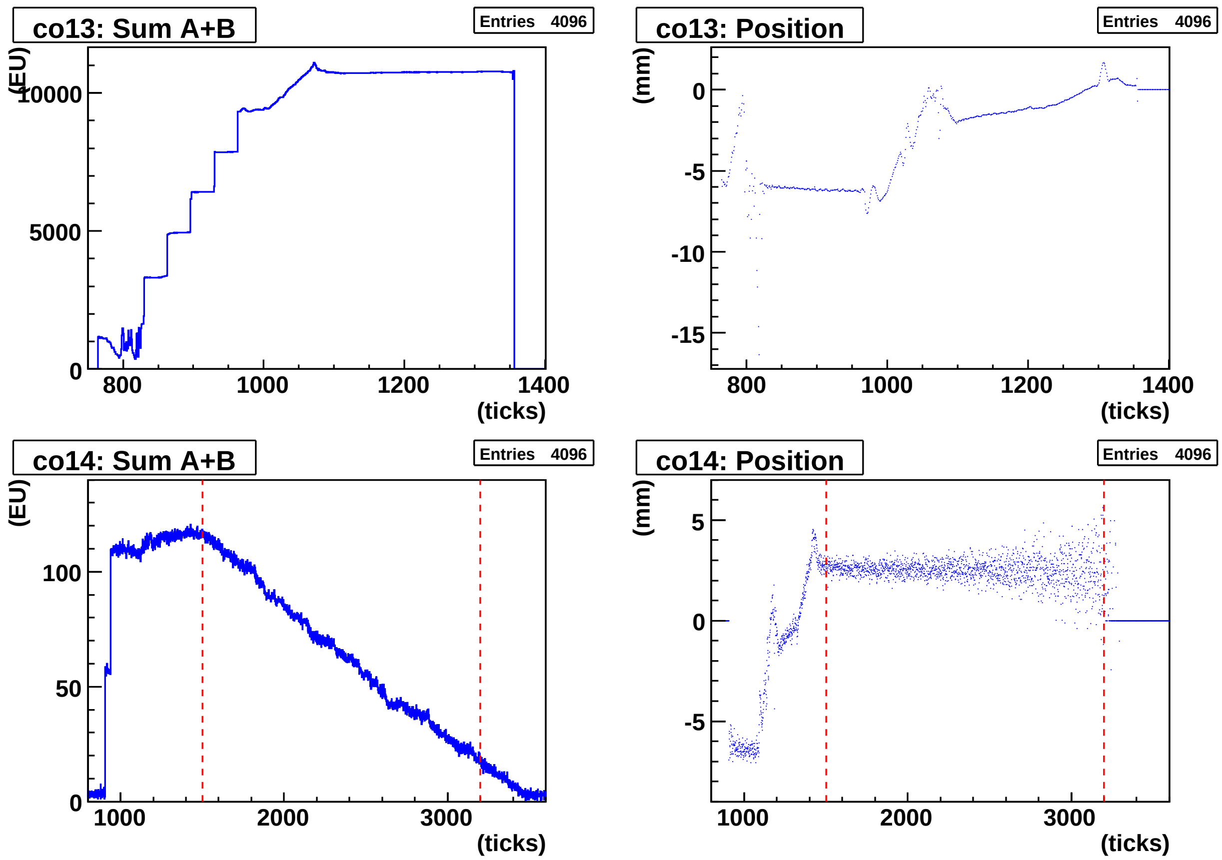

Figure 7: Closed orbit sum and position data for two other MI states, for the H BPM 412. The upper two plots show the information for mixed mode, slip stacking plus beam to NUMI. The lower two plots show the information for the slow spill to MTEST/MIPP. The data between the red dashed vertical lines was used to measure the closed orbit position resolution as a function of sum signal.

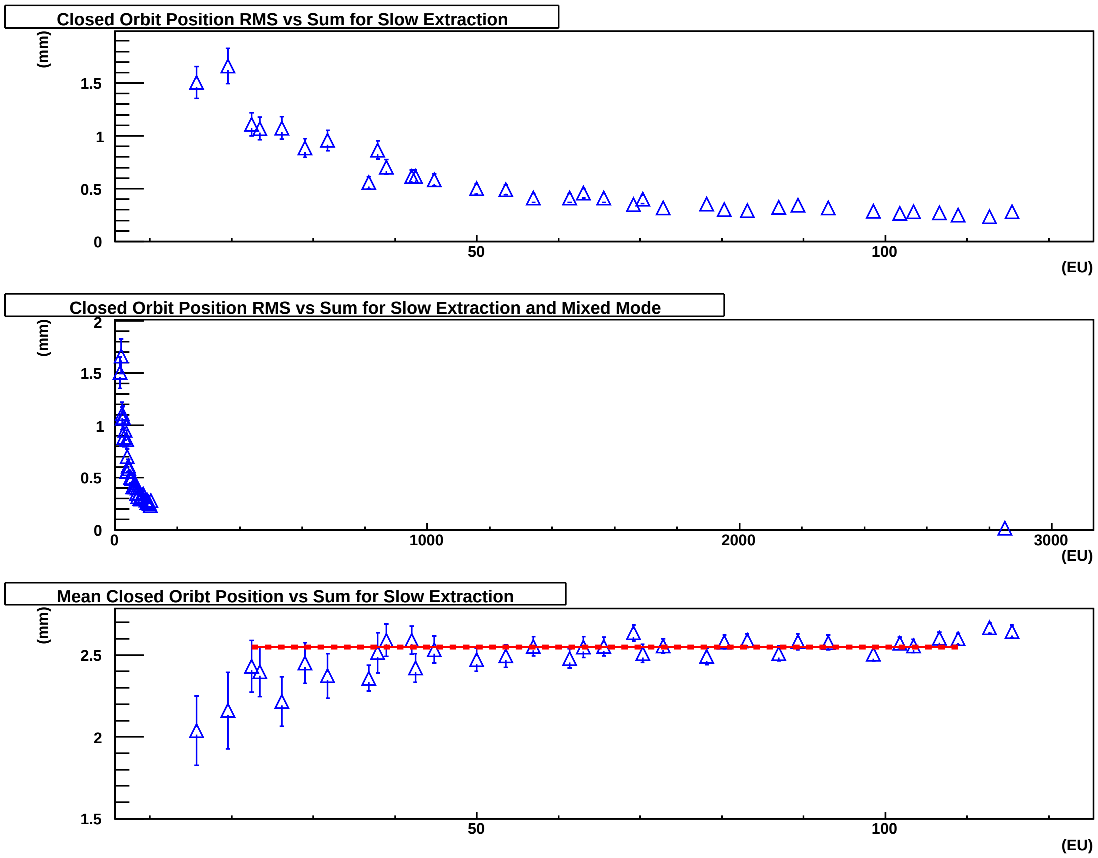

Figure 8: The top plot shows the closed orbit resolution, measured as a function of sum signal for the data between the red dashed vertical lines in the bottom part of Figure 7. The middle plot shows the same data as the top plot, plus the data point from the mixed mode closed orbit data shown in Figure 6. The bottom plot shows the position as a function of sum signal, with points in one to one correspondence with the top plot. The solid red vertical line is the mean position, excluding two points at each end; the dashed vertical lines are the $\pm$ 1 σ errors on the mean.